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Mobile Luminance Data Collection System User Manual

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Developing Luminance-Based Mobile Highway Delineation Equipment and Level of
Service Guidelines for Safe Nighttime High-Speed Travel
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MOBILE LUMINANCE DATA COLLECTION SYSTEM USER MANUAL

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Disclaimer

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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Quick Start

Has it been awhile since you used the system, but you are really familiar with it? Well, this is the place to start. If this is your first time to use the system, we encourage you to skip to the introduction.

BEFORE YOU START

The first thing you need to think about is what your goal is in using this system and what level of user you are. The system can be operated using the open source code, but for the novice user, this could pose a problem because code can be altered inadvertently. Furthermore, to run the open source code, you must have National Instruments LabVIEW installed on your local machine. Thus, this manual provides an executable code that can be installed to avoid these problems. Those of you who are advanced users can use the open source code to run the software, but the only reason to do this would be if you are considering software changes to the original code to modify the graphical user interface (GUI) or the internal functionality of the software to serve a particular purpose.

FOR MORE INFORMATION

Refer to the various chapters within this document if you have questions. If you do not find what you need, use the contact information listed at the end of the Introduction to obtain further guidance.

Introduction

While nighttime driving volumes are lower than daytime, the percentage of crashes with respect to volume is higher, so it is critical that transportation agencies do everything economically possible to improve nighttime driving safety. One crucial part of nighttime driving safety is the visibility of traffic control devices (TCDs). This manual provides a description of the mobile luminance data collection system designed for TxDOT to evaluate the nighttime visibility of TCDs. The manual also contains detailed guidance on how to install the software and hardware, how to use the system, and how to conduct a post-processing analysis of images taken of the nighttime driving scene.

PURPOSE

The purpose of this user manual is to guide field personnel through the installation and use of the mobile luminance data collection system as well as the general procedure for post-processing the data and troubleshooting the equipment and associated software. The mobile luminance data collection system is designed to measure luminance of the visual field in front of the data collection vehicle for the purposes of evaluating the effectiveness of delineation devices, such as pavement markings, pavement markers, delineators, and chevrons. The system may also be used to evaluate other traffic control devices, such as signs. While it would be possible to measure roadway lighting as well, the dynamic range of the existing cameras is such that it is not currently practical.

INTENDED USERS

While the system has been designed for both advanced and novice users, it is recommended for use by advanced users whose primary job is to quantify the effectiveness of various traffic control devices. An advanced user would be someone with at least a moderate to advanced understanding of making photometric measurements using state-of-the-art technology. An advanced user would also have a clear understanding of retroreflectivity, illuminance, luminance, and their interaction with respect to observation angle and light source. While the

authors have detailed many key aspects of installing and using the equipment and software, the authors believe an advanced user would not only be able to use the equipment effectively but also be able to:

- Quickly ascertain whether there is a problem with the data.
- Troubleshoot why the data are in error.
- Take quick corrective action.
- Over time, be able to see how to improve the system, software, and/or procedure more effectively than a novice user.

RELATED DOCUMENTS

The authors recommend reviewing the technical report that documents the research under which this manual was written, *Report FHWA/TX-12/0-6647-1: Developing Luminance-Based Mobile Highway Delineation Equipment and Level of Service Guidelines for Safe Nighttime High-Speed Travel*. An electronic copy of the report is available on the CD-ROM that accompanies the written copies of this manual.

COPYRIGHT

As the software detailed in this manual was developed for TxDOT using public funds, there are no copyright restrictions. Other supplemental software that is not required but may be used in conjunction with this software, such as LabVIEW®, MatLAB®, and Microsoft Excel, copyright restrictions do apply. TxDOT will be required to purchase LabVIEW® and MatLAB®, if members of its organization require modifying the software. As for Microsoft Excel®, it and all of Microsoft® Office 2010 are already included with the laptop provided. Any additional laptops or updates to the software, such as later versions, will require TxDOT to obtain additional copyrights.

CONTACT INFORMATION

All software or hardware issues may be addressed to the primary author stated below, or internally within TxDOT to Alan Hagler.

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System Overview

There are two primary software packages discussed in this section. One is the data collection graphical user interface (GUI), and one is the data reduction GUI.

KEY FEATURES

The key features of each of the software packages are noted below.

- **Data Collection GUI:**
 - Collect luminance data from the road scene in front of each system camera.
 - Set thresholds that can be used to assess TCD pass or fail based on minimum luminance established prior to data collection.
 - Geocode all data.
 - Collect data using one or more cameras.
 - Complete limited in-field image processing.
- **Data Reduction GUI:**
 - Analyze images taken from the field with regard to their performance based on luminance.
 - More accurately access TCD performance of discrete, small, angular-sized TCDs, such as reflectorized raised pavement markers (RRPMs) and delineator posts.

SYSTEM STRUCTURE AND OPERATION

The purpose of the system is to measure nighttime roadway luminance. The cameras have lenses that focus the incoming light through a V-Lambda filter onto the internal imaging chip, and then those images can be viewed in real time and recorded to the computer for further evaluation. All of these data are geocoded using global positioning system (GPS) data, and the data files can also be appended to indicate whether some particular TCD component, such as the right edge, is failing by TxDOT requirements, which are set to meet or exceed FHWA requirements. The system structure was built in a modular fashion to allow for easy updating to

new technologies and to add additional technologies, such as 3-Dimensional Light Detection and Ranging (3D LIDAR), to more accurately assess TCD placement and possibly manage assets. It was not within the scope or budget of the project that this version of the manual was developed under to incorporate 3D LIDAR.

SYSTEM REQUIREMENTS AND INVENTORY

Before getting started, you will need to assess the capabilities of the system on which you wish to install the software. The authors have detailed the system requirements, listed in Table 1, based on what they used to develop the mobile luminance data collection system. It may be possible to use a system with lower specifications, but the authors cannot confirm whether the system will operate as described in this manual if using different specifications. The same will hold true as newer operating systems are developed; the authors cannot confirm whether the mobile luminance data collection system software will operate on newer versions of Windows 7 or later operating systems. Microsoft Excel in Office 2010 will be needed to read the geocoded data files and complete any post-processing analysis. Other spreadsheet programs may be used, but the authors have only tested Excel® in Office 2010. In addition to the hardware and software specifications for the computer, the authors have detailed the system devices that make up the mobile luminance data collection system. A CD-ROM containing both the executable code and the source code, the user manual, and the final report will be provided with each hardcopy of the user manual.

Table 1. System Specifications.




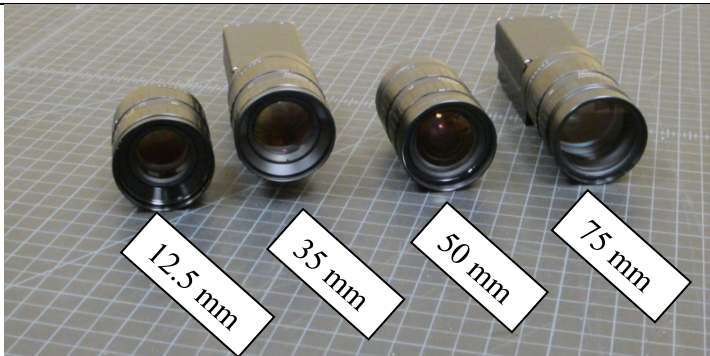
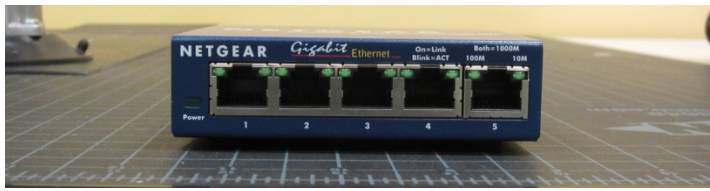

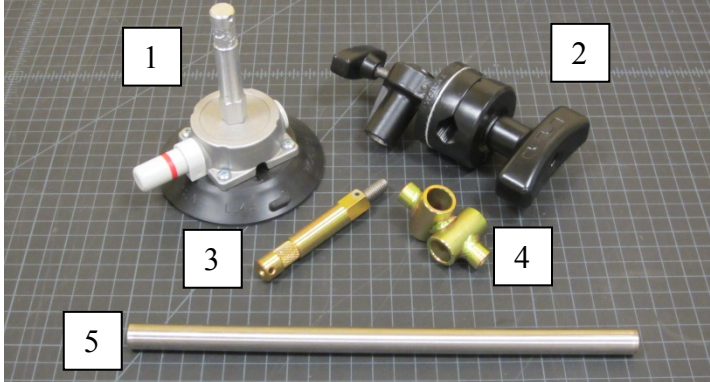

Computer	
Dell Latitude E6520 Laptop 2.5 GHz i5-2520M 4 GB DDR3-1333 MHz RAM 256 GB Solid State Drive Gigabit Ethernet Port USB 2.0 Port (4) e-SATA Port Bluetooth Wireless Wireless LAN [802.11a/b/g/n]	
Software	
Microsoft® Windows® 7 (64-bit) Microsoft® Office 2010 National Instruments LabVIEW® TTI Luminance Data Collection Software TTI Data Reduction Software	
Qstarz 818XT 10 Hz GPS Receiver	
Camera	
Basler Scout Sca1400-17gm (2) with V-Lambda Filter	

Table 1. System Specifications Continued.

<p>Fujinon 1" 1.5 Megapixel Lenses (4)</p> <ul style="list-style-type: none"> • 12.5 mm [CF12.5HA-1] • 35 mm [CF35HA-1] • 50 mm [CF50HA-1] • 75 mm [CF75HA-1] 	
<p>Ethernet Switch</p>	
<p>PowerLine Inverter 12VDC/120VAC 200W</p>	
<p>Suction Cup Camera Mount</p> <ol style="list-style-type: none"> 1. 4.5" Suction/Vacuum Cup with 3/8-16 Spud 2. 2-1/2" Hollywood Grip Head by Matthews Studio Equipment 3. 5/8" Baby Spud with 3/8-16 Female Thread at Base and Allen Key Set Screw Stainless 1" x 3/8-16 4. Baby 5/8" Cross 5. Redrock 12" 15 mm Stainless Rods 	
<p>Bogen Manfrotto Mini Ball Head 494</p>	

Note: Where there are multiples of the same item, the quantity is indicated within parentheses.

Installing, Starting, and Stopping the Software

The first thing you need to think about is what your goal is in using this system and what level of user you are. The system can be operated using the open source code, but for the novice user, this could pose a problem because code can be altered inadvertently. Furthermore, to run the open source code, you must have National Instruments LabVIEW® installed on your local machine. Thus, this manual provides an executable code that can be installed to avoid these problems. Those of you who are advanced users can use the open source code to run the software, but the only reason to do this would be if you are considering software changes to the original code to modify the GUI or the internal functionality of the software to serve a particular purpose.

Regardless of what you decide to use, the authors have detailed the use of the executable code because only advanced software users should consider changing the code. An advanced software user is one who knows LabVIEW® extensively and thus would not need any guidance on how to install LabVIEW® and its various components. An advanced software user should not be confused with someone who has an advanced understanding of collecting photometric data but may only have a novice understanding of software development.

INSTALLING THE SOFTWARE

The software installation instructions below are for the executable software files. To execute the source code files for the mobile luminance data collection software, you will also need to install National Instruments LabVIEW® 2011 or later version. To execute the source code files for the data reduction software, you will need to install MATLAB® 2010 or later version. To install these additional programs or the executable programs discussed below, you must have administrative rights.

Step 1: Copy Files from CD-ROM

- ✓ Turn on/log on to the computer, and insert the CD into the CD drive.
- ✓ Copy all folders from CD-ROM to desktop.

Step 2: Mobile Luminance Data Collection Software

- ✓ Select the folder labeled Mobile Luminance Software Executable.
- ✓ Before running the executable file (.exe file), install the supporting modules and toolkits, such as NI LabVIEW Run-Time Engine 2011, NI Vision Run-Time Engine 2011 SP1, etc. The install file can be found in the following directory: .\Mobile Luminance Software Executable\Install\Volume\Setup.exe.
- ✓ Double-click the Setup.exe icon. The authorization pop-up window shown in Figure 1 will appear. Click Yes to continue.

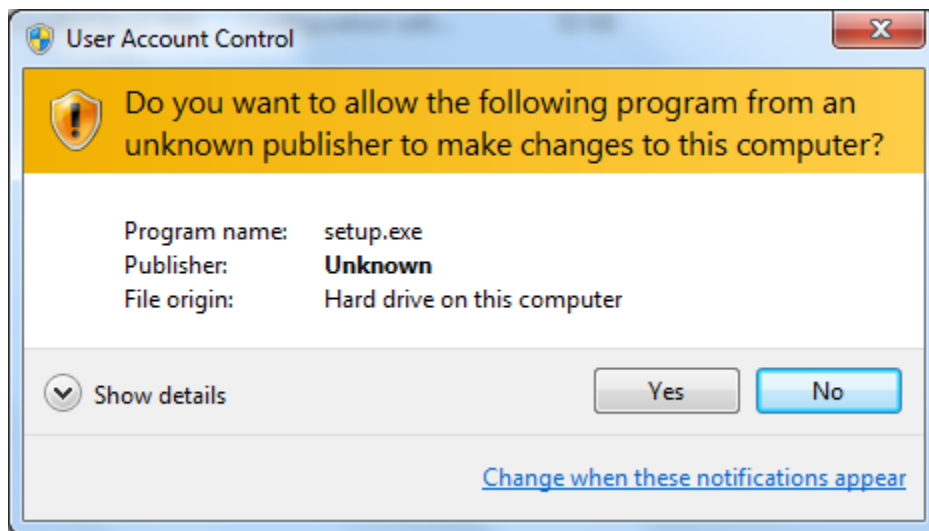


Figure 1. Authorize the Mobile Luminance Software to Install.

- ✓ Installation will begin by displaying the window shown in Figure 2. Select the desired directories in which the software program and its supporting modules will be installed, and then click Next.

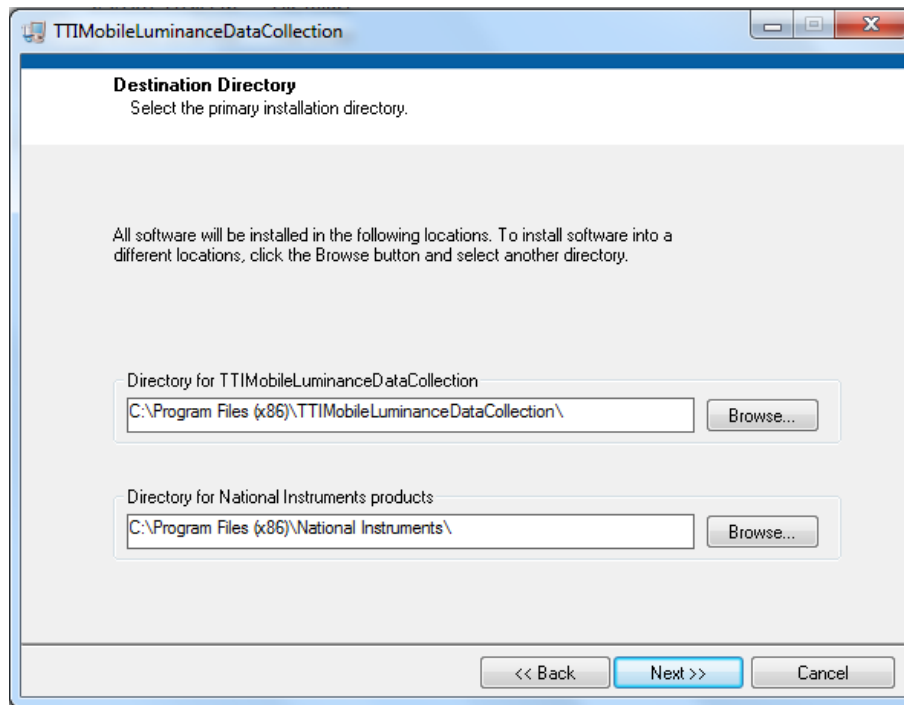


Figure 2. Select Directories for Mobile Luminance Software Installation.

- ✓ Accept the license agreement, as illustrated in Figure 3, and then click Next.

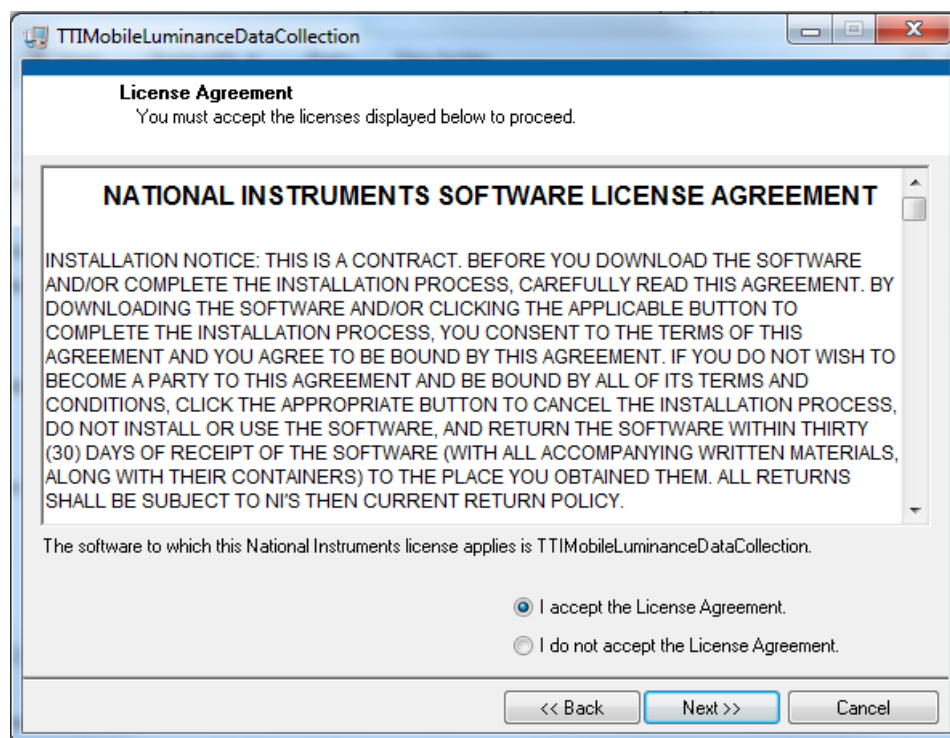


Figure 3. Accept License Agreement for Mobile Luminance Software.

- ✓ Review additional support in the installation list, as shown in Figure 4, and then click Next.

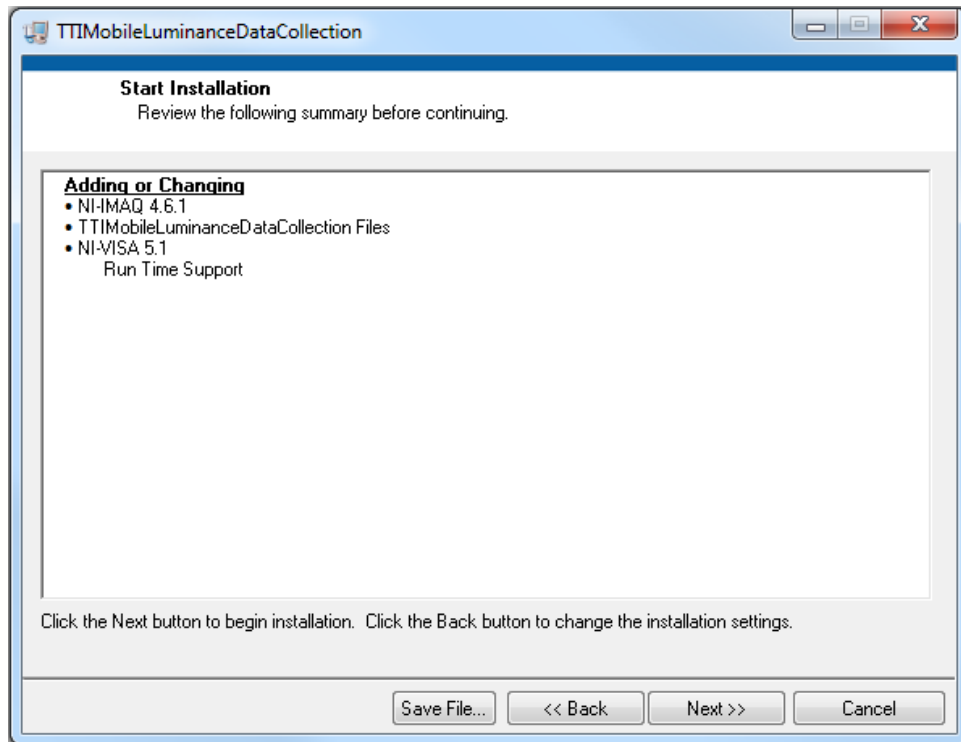


Figure 4. Review Additional Support for Mobile Luminance Software.

- ✓ If asked, enter your full name and organization. This information will be used to complete your software registration.
- ✓ Follow the instructions on the screen to finish installing and activating LabVIEW and its toolkits.
- ✓ After the installation is complete, open the software by either finding the executable file—TTIMobileLuminanceDataCollection.exe—in the selected directory or clicking on the Mobile Luminance Software shortcut, which can be found by clicking the windows Start button and then clicking on All Programs, as shown in Figure 5.

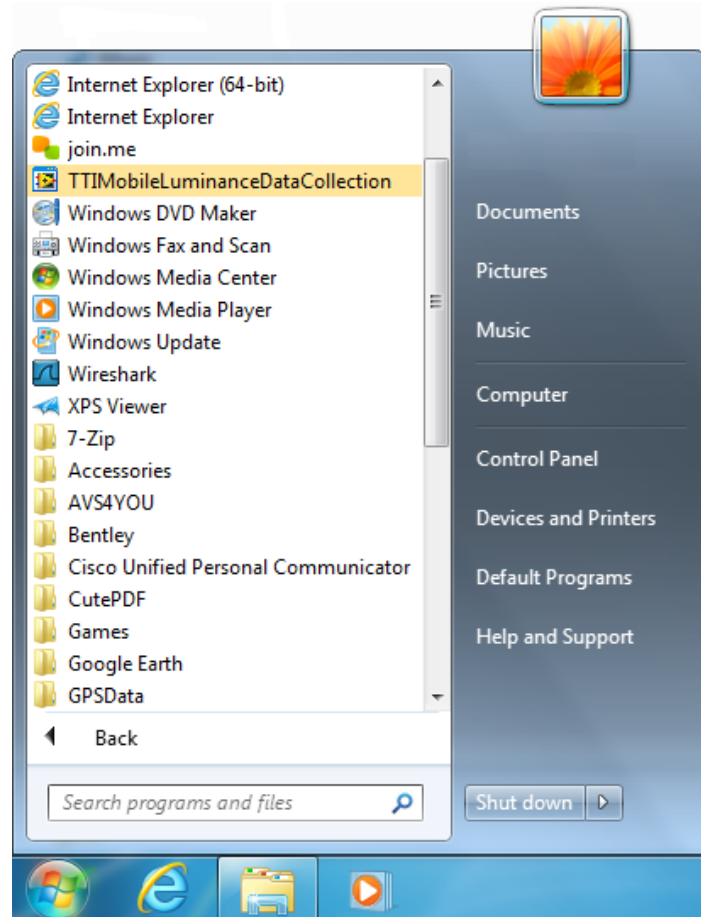


Figure 5. Shortcut to Mobile Luminance Software.

Step 3: GPS

- ✓ Select the folder labeled GPS Driver.
- ✓ Select the folder labeled Qstarz GPS.
- ✓ Select the folder named MT3329_USB_Installer.
- ✓ Select the InstallDriver application, as shown in Figure 6.

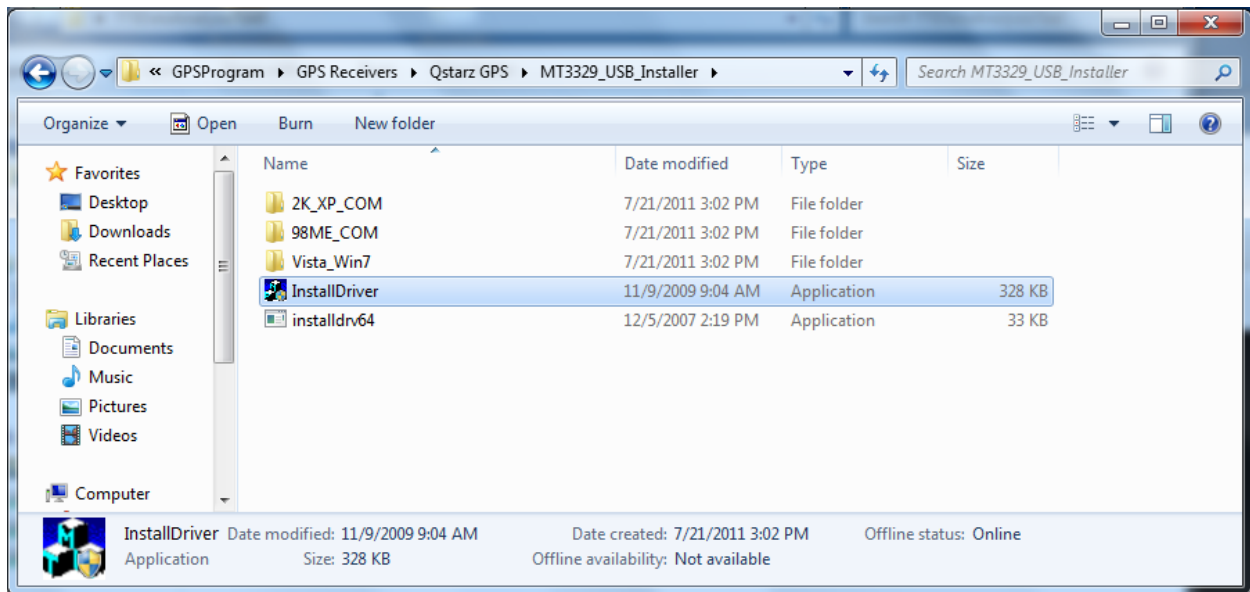


Figure 6. GPS Driver Installer.

Step 4: Data Reduction Software

- ✓ Select the folder labeled Data Reduction Tool.
- ✓ If you are running a 32-bit operating system, double-click the folder named Install for 32-bit. If you are running a 64-bit operating system, double-click the folder named Install for 64-bit. (Since the remaining steps for installing the program in different operating systems are the same, the following instructions are for the 64-bit version but work for the 32-bit version as well.)
- ✓ In the Install for 64-bit folder, double-click the DataReductionTool_pkg.exe file to unzip all installation files. A pop-up window will show details of all Data Reduction Tool files, as demonstrated in Figure 7.

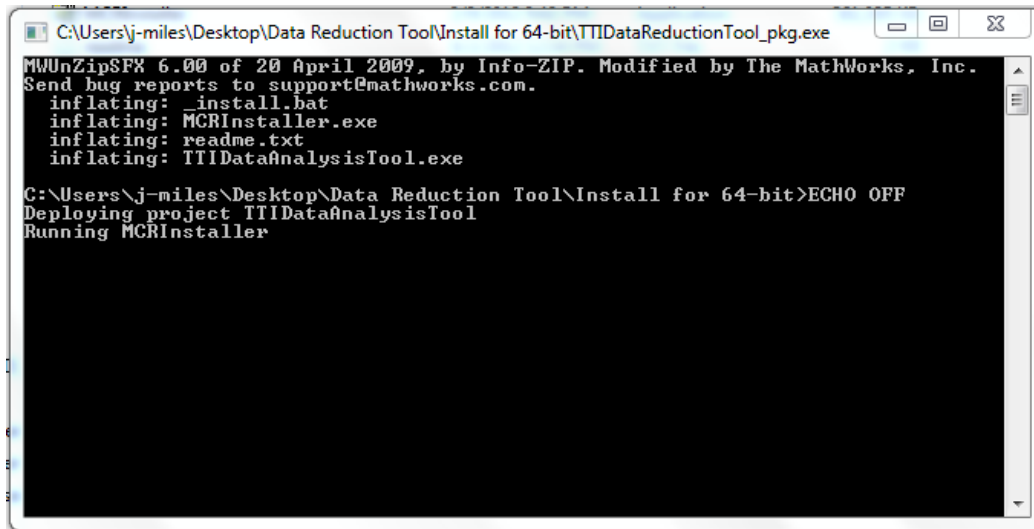


Figure 7. Unzip Installation Files for Data Reduction Tool.

- ✓ Before you can complete the installation, you will need to grant authority by clicking Yes in the pop-up window, as shown in Figure 8.

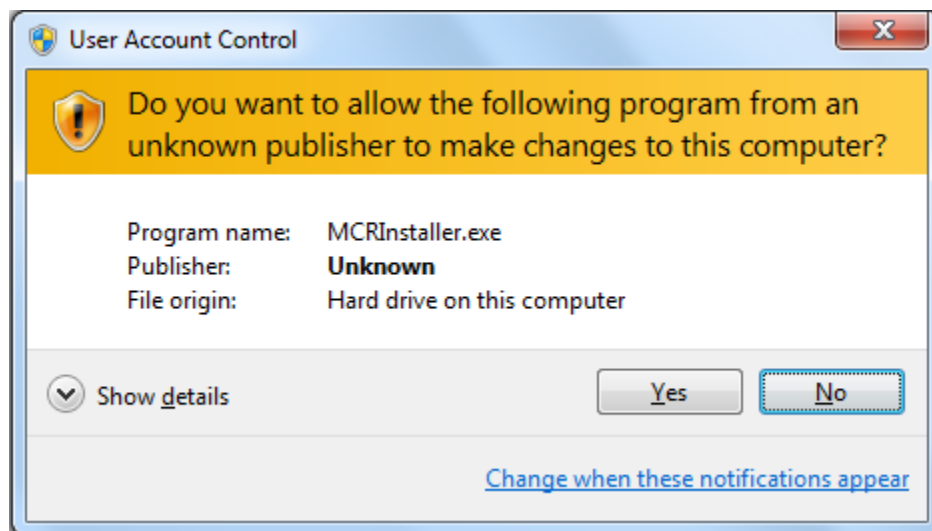


Figure 8. Grant Authority for Data Reduction Tool.

- ✓ After you have inflated all necessary files, MATLAB® Runtime Installer (MCRInstaller.exe) will automatically start, as shown in Figure 9. Click Next to continue.

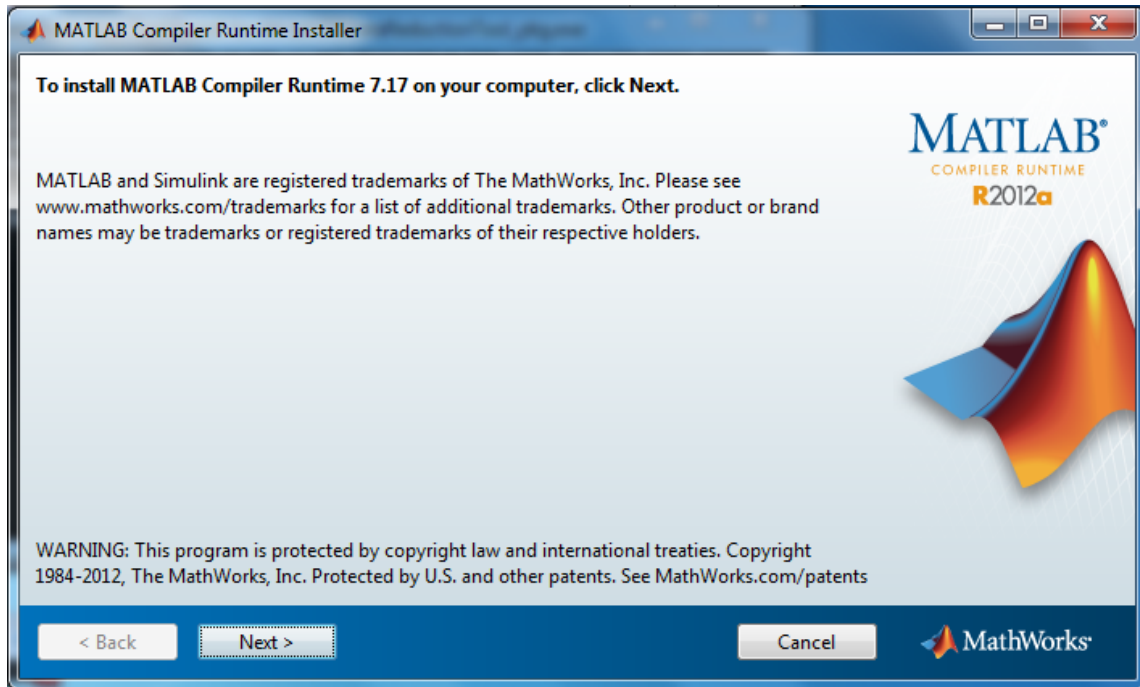


Figure 9. MATLAB Runtime Installation.

- ✓ Accept the license agreement, as illustrated in Figure 10, and then click Next.

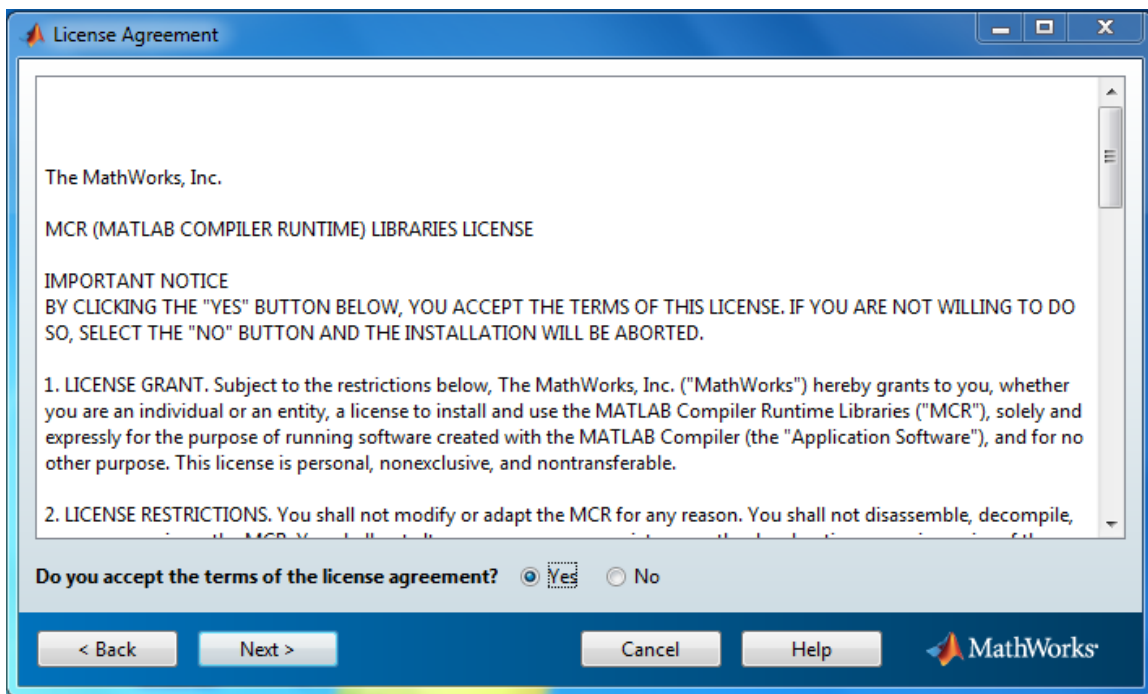


Figure 10. Accept License Agreement for MATLAB Runtime Installation.

- ✓ View the installation information, and then click the Install button (see Figure 11).

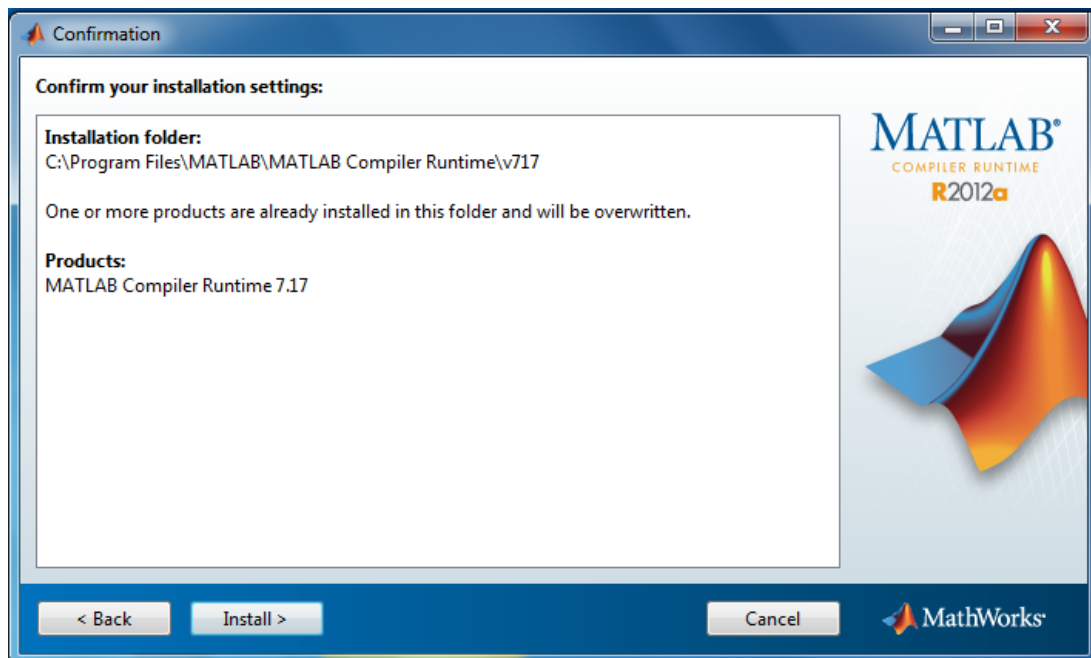


Figure 11. Installation Information for MATLAB Runtime.

- ✓ Click Finish to complete the installation, as shown in Figure 12.

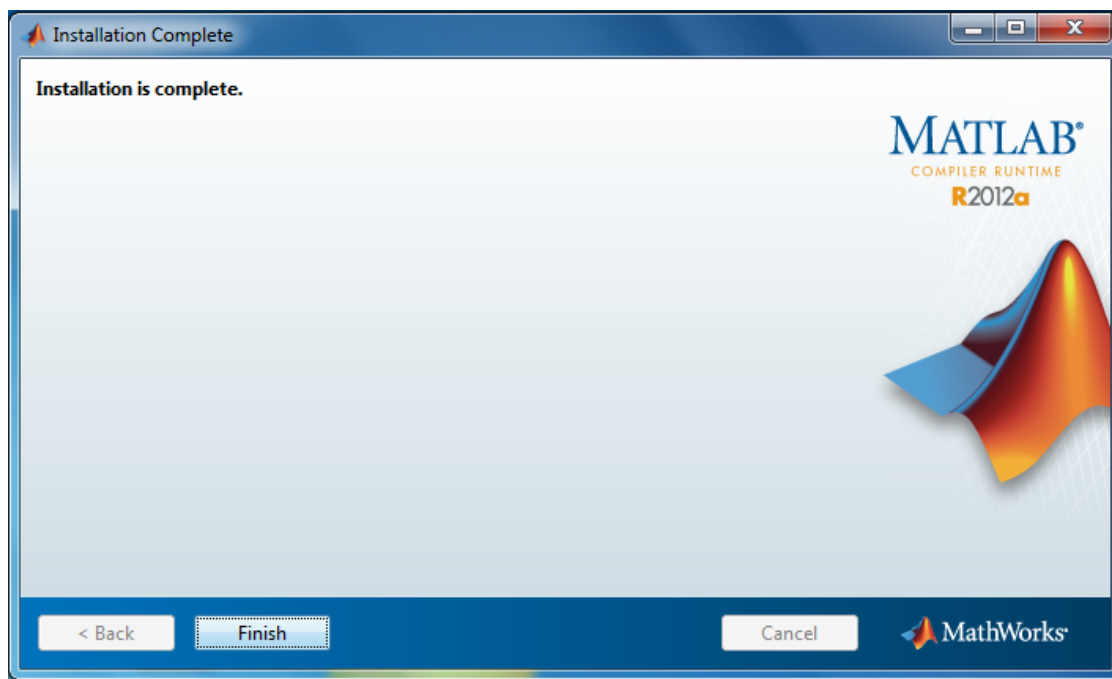


Figure 12. Finish Installation of MATLAB Runtime.

- ✓ Locate and double-click on the TTIDataReductionTool.exe file to start the program.
- Figure 13 shows both the directory with the executable file selected and the GUI of the software with an image open.

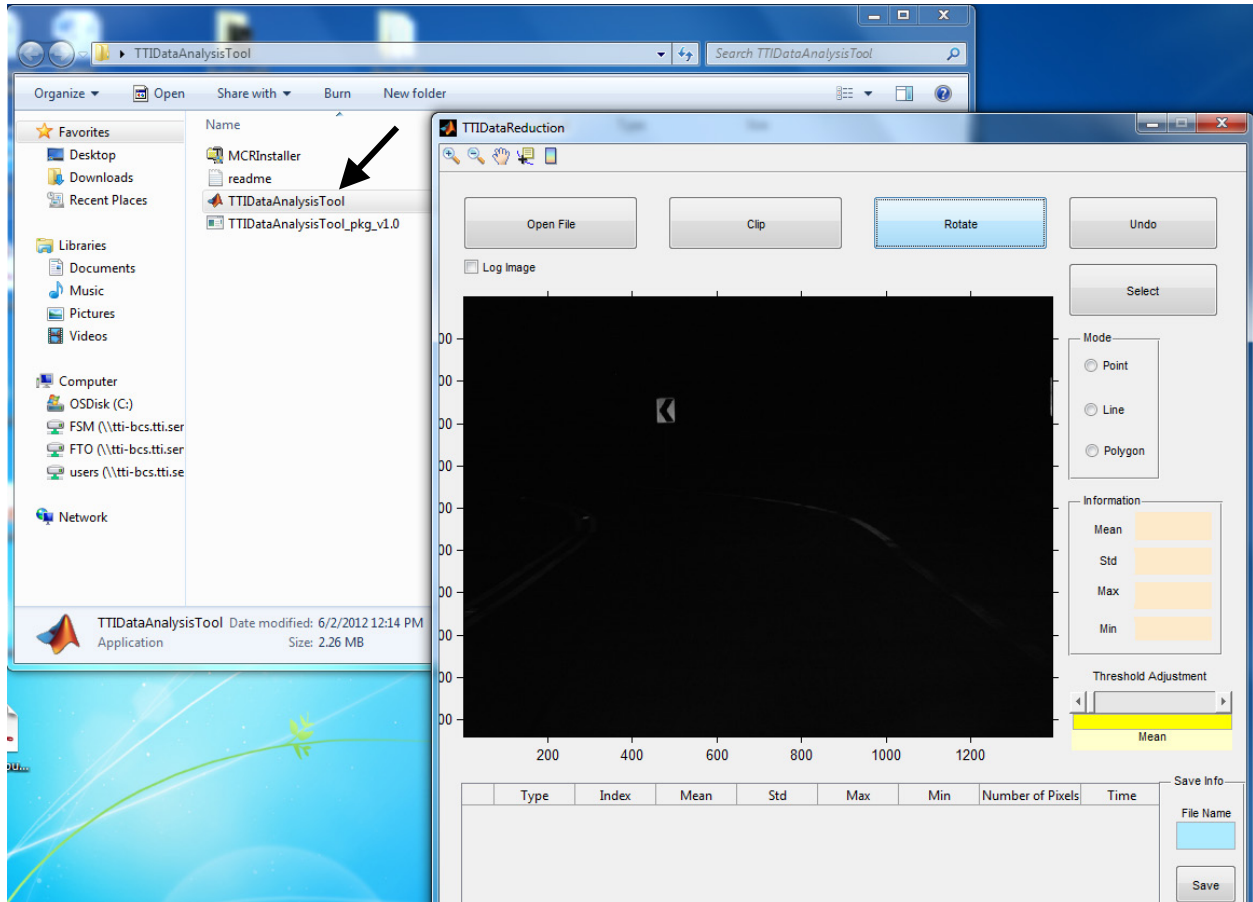


Figure 13. TTIDataReductionTool.exe File.

CONNECTING AND TESTING HARDWARE COMPONENTS

It is more difficult to install the hardware components in a vehicle than in the office. Therefore, this manual details only the in-vehicle installation instructions. The instructions can easily be modified for use in the office prior to in-field data collection for in-office testing and/or calibrations.

Prior to installing any of the equipment in the vehicle, the user should first assess whether he/she will be using one or multiple cameras for data collection, and then test the equipment in

the office. The use of multiple cameras for data collection can be beneficial, but this configuration is slightly more complicated to set up. The primary complications are power management, camera alignment, and cable management.

The power management concern involves how many cords you need to plug in and what their power requirements are. Each camera requires one 120VAC plug connection and one RJ45 connection. If two cameras are used, then an Ethernet switch or router is necessary, which also requires a power cord. While the GPS device requires power, it is supplied through the USB connection, which means it is just an additional cable to consider. The last component is the laptop computer, which can run off a battery, but the authors recommend powering it directly through the 120VAC plug. Thus, if the user operates one camera, he/she will require two power connections running off one 120VAC 200W power inverter with two outlets, but if the user operates two cameras, he/she will require four power connections and two inverters. There are inverters with four 120VAC power connections, but they are expensive, large, and generally far exceed the power requirements. Furthermore, the total current drawn through an inverter cannot exceed the capacity of the fuse associated with the 12VDC power connection. The fuses are often 20 amps, but it is recommended that continuous currents be kept to under 15 amps with peaks under 20 amps based on field experience. However, the authors recommend checking each vehicle's design specifications and following them.

The next consideration is camera alignment. The user needs to first consider how he/she intends to use the system. The system provides luminance data based on the orientation of the cameras. The authors recommend that the user set each camera at approximate driver eye height for a standard driver. For consistency, it is recommended that he/she use the center of the headrest as a reference height. The authors recommend using the lateral offset along the centerline of the vehicle or toward the passenger side in a location that does not obstruct the driver. The complication with two cameras involves setting up the mounting device and cameras so that they do not conflict with each other or the view of the driver.

The last complication associated with two cameras is cable management. It is important to install the cables to minimize the likelihood of them binding, snagging, or entangling. If the cables bind, the user could damage the cables or the devices he/she is connecting. Snagging the cables will likely disconnect, if not damage, the connection points between the cables and the

hardware. Entanglement increases the likelihood of binding and snagging, and all three conditions are potential hazards to the equipment operators.

Each of these potential points of complication for using more than one camera are not meant to discourage their use but to alert installers about things they should consider during installation. As it is believed the two-camera setup is the most difficult, this manual includes step-by-step vehicle installation from the perspective of a two-camera installation. It is also important to note that camera alignment and cable management should be considered for a single camera setup. Specific guidance will be provided throughout the text.

Step 1: Install Cameras

While sitting in the driver seat, install the suction cup mount (without the cameras) on the windshield inside the vehicle in a position that least obstructs the driver's forward view. This can be done by mounting the suction cup near the rearview mirror, which already obstructs the driver's view, or near the dash, where the hood obstructs some of the driver's view. Potential problems near the mirror can occur if the placement of the suction cup:

- Infringes on the movement of the rearview mirror.
- Prevents a durable seal, as can result from some window tinting techniques, such as dot matrix, used around the rearview mirror (see Figure 14).



Figure 14. Potential Mounting Problem from Tint and Proximity to Rearview Mirror.

Regardless of the final position, you should consider access to all adjustment points in the suction cup mount and the camera mounts to avoid obstructions that could impair the ability to make adjustments in the camera alignment. Figure 15 shows two conflicts. The first conflict is between the grip head that holds the supporting rod for the camera mounts and the knobs on the camera ball head mounts. The heads can be turned to tighten the grip, or an additional baby cross can be used. While the baby cross has a considerably smaller footprint than the grip, it also requires an Allen wrench to adjust. These adjustments aid in aiming the cameras, minimizing the obstruction of the driver's forward view, and minimizing camera vibration. With the exception of the potential tinting issue, affixing the camera mount near the bottom of the windshield has identical concerns to placing the suction cup mount near the top of the windshield near the rearview mirror.

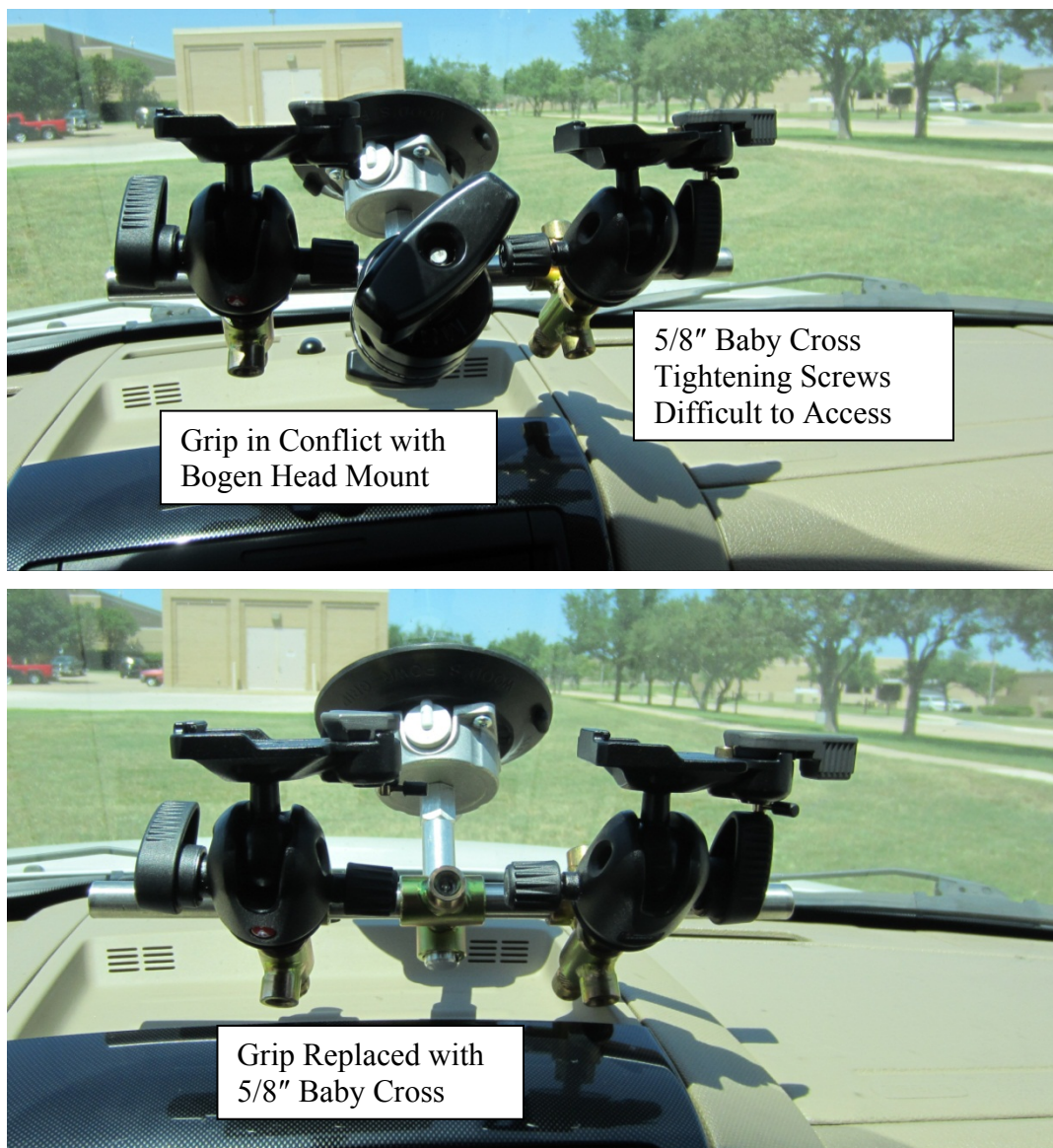


Figure 15. Potential Conflicts with Adjusting Camera Alignment.

Prior to installing the cameras in the mounts, you must mount the lenses to the cameras, if not already done, and adjust their f-stop. The recommended default f-stop for each camera lens is 2.8. After checking the f-stop, secure it with the locking screw, as Figure 16 illustrates. The last thing before mounting the camera onto the ball head mount is securing the quick release plate to the bottom of the camera mounting plate. Once the camera quick release plate is secure, the camera can be installed in the ball head mount. Ensure that the quick release latch locks in place and the lock for the quick release is secure, as indicated in Figure 17.

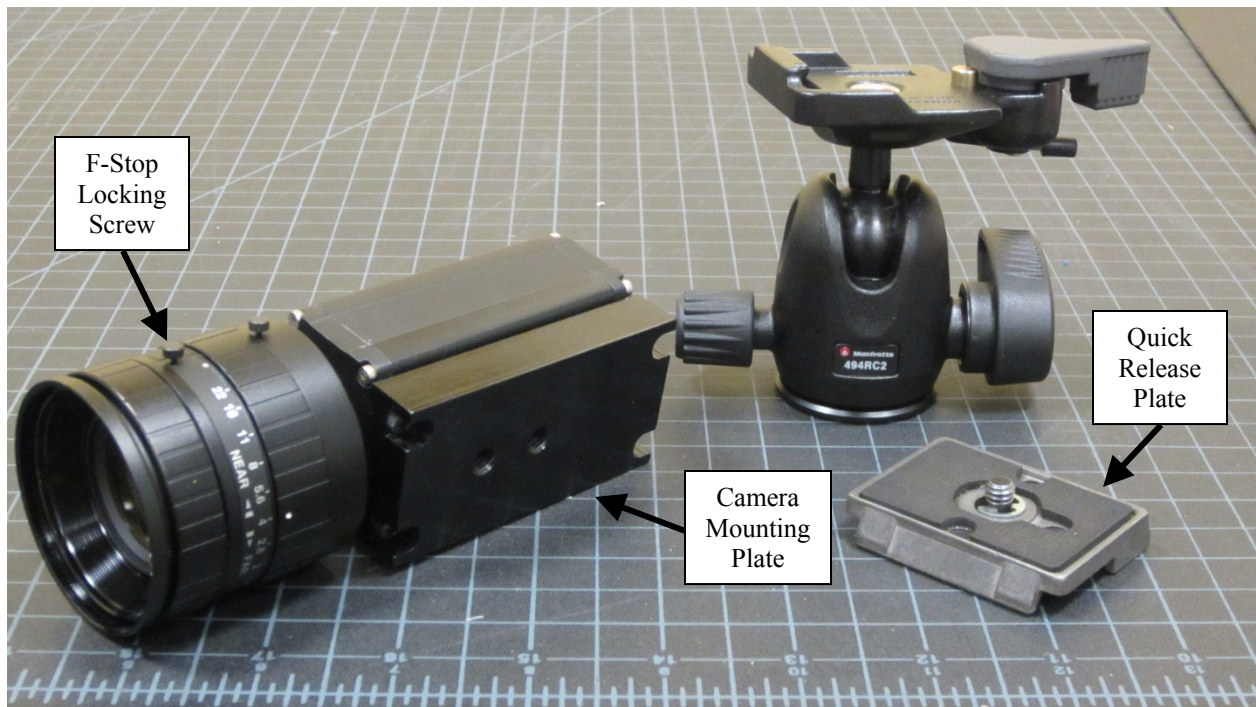


Figure 16. Set F-Stop.

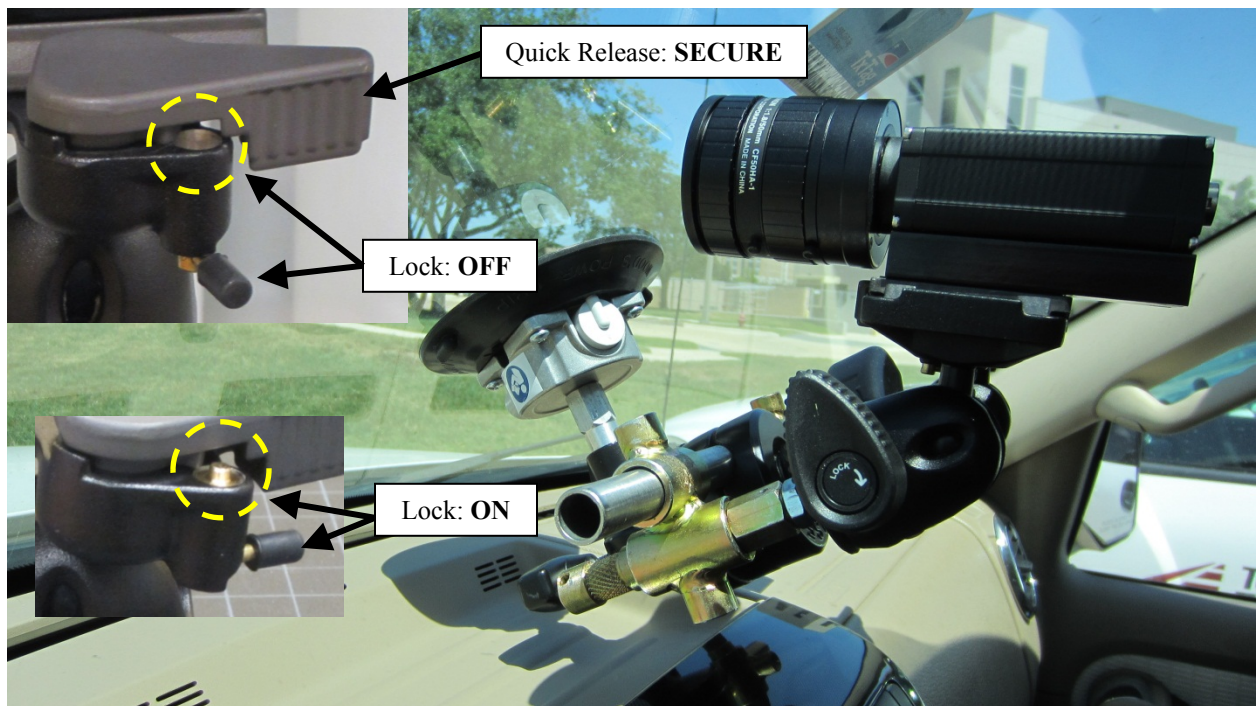


Figure 17. Camera Mounted prior to Wiring.

Step 2: Install GPS

There are several ways to mount the GPS, but to minimize the number of obstructions on the front windshield and the wiring, the GPS should be attached to the top of one of the cameras using Velcro (see Figure 18). Turn the GPS power switch to the 10 Hz position.



Figure 18. GPS Mounted to Camera.

Step 3: Install Cabling

To help with cord management, both during measurement and for storage, a Velcro strap should be attached to each set of camera cables and other accessory cables. Use this Velcro strap to fasten each set of cables to the camera mount and other cables in order to minimize binding, snagging, and entanglement. The authors recommend that the user runs all cables between the camera mounts. Tie the one GPS cord to the set of cords emanating from the back of the camera to which it is mounted (see Figure 19).

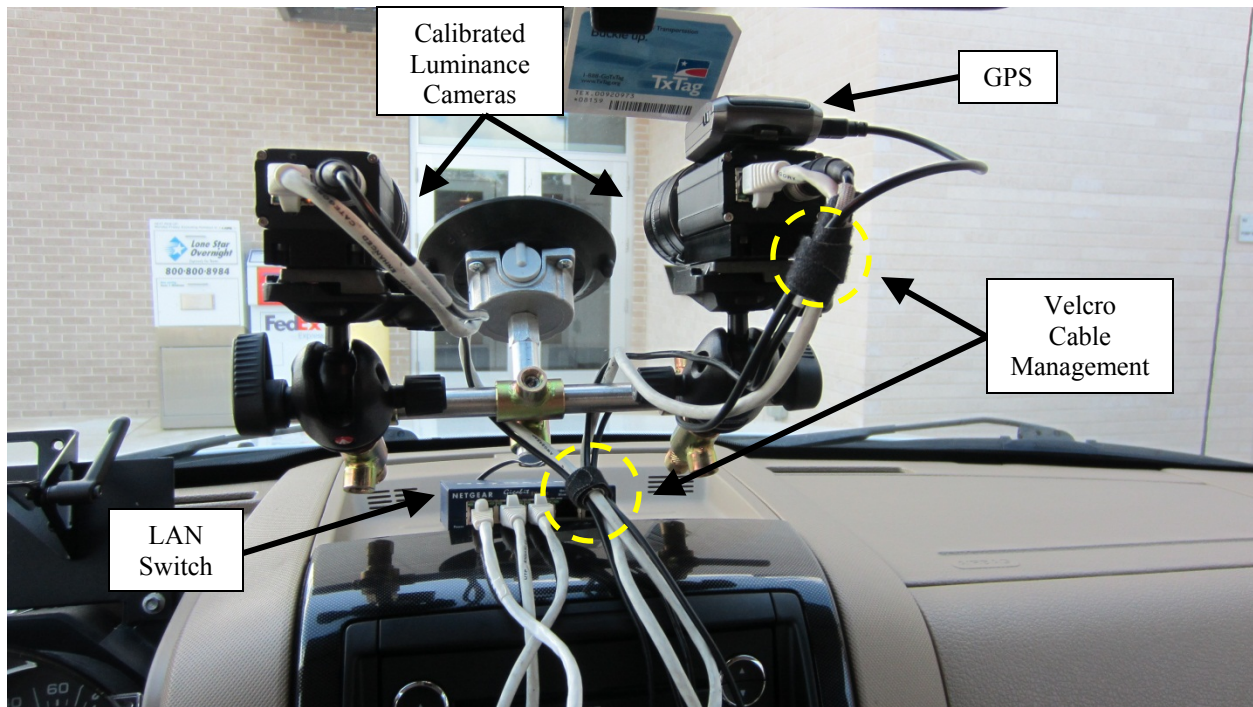


Figure 19. Cable Setup Attached to Cameras and GPS.

Step 4: Install Computer

Plug each cord into the computer, turn it on, and log on. Leave enough cable to allow the person collecting the data ample range of movement without binding/snagging cables (see Figure 20). This will make the long hours of late-night data collection more comfortable, while minimizing the likelihood of damaging a computer port connection or a piece of equipment attached to the computer, such as the cameras or GPS receiver. When possible, secure the laptop on an in-vehicle storage tray to minimize its movement and improve user comfort because a laptop placed in the user's lap can become hot and encourage poor posture, which can fatigue the equipment user.

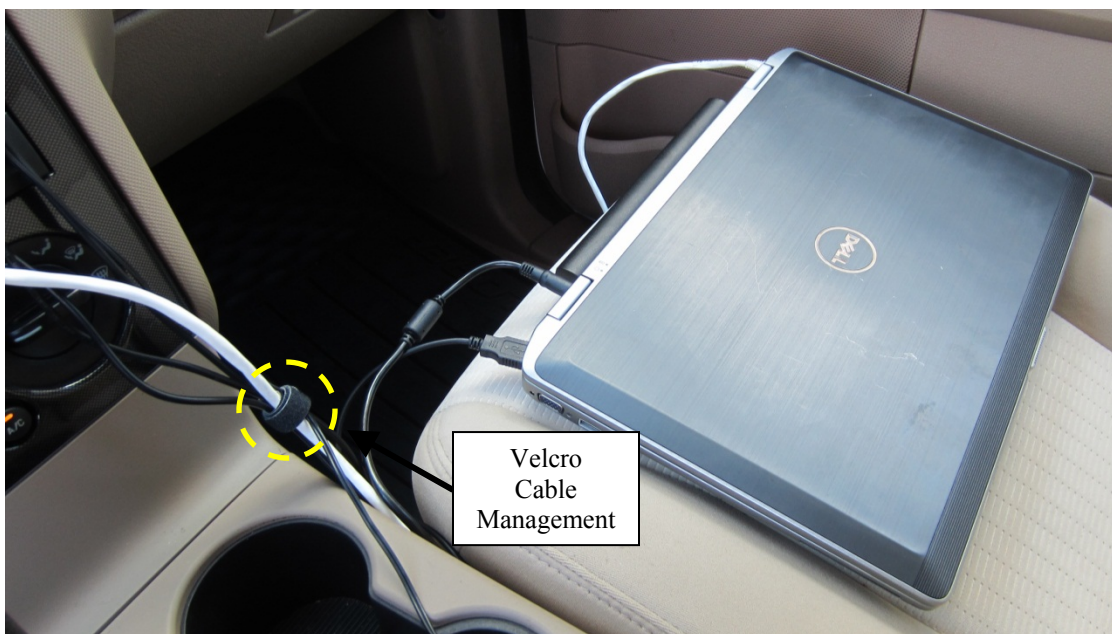


Figure 20. Cable Setup Attached to Computer.

Step-by-Step Instructions for Using the Software

This chapter details the step-by-step procedures the user should follow when using this system. This system is meant to collect nighttime TCD luminance data and process it. The authors devised two different software packages to accomplish this, and these two different software packages are discussed in this section.

INSTRUCTIONS

Mobile Luminance Software

The authors see using the Mobile Luminance Software (MLum) in three capacities:

- Image Collector Evaluation (ICE) Mode.
- Semi-Automated Mobile Pass Level Evaluation (SAMPLE) Mode.
- Calibration Mode.

ICE Mode

This is the simplest system setup. The user will set the system to constantly record images for post-processing. The benefit of this mode is that the user will have near-continuous documentation of the performance of the TCDs along a given roadway. Furthermore, only one user is required for the data collection. This mode is only recommended when TxDOT is short of staff and for short roadway segments because if a user collects one image a second at 60 mph along a 10-mile segment of roadway, he/she will collect around 600 images. Evaluation of a single image takes between 1 and 15 minutes depending on the level of complexity, so if all images were analyzed, it would take a minimum of 10 hours, or 1 hour per 1 mile of roadway.

When using the ICE Mode, the following steps should be followed:

STEP 1: Select the executable MLum software to open it. See the icon marked with the yellow oval in the top right corner of Figure 21.

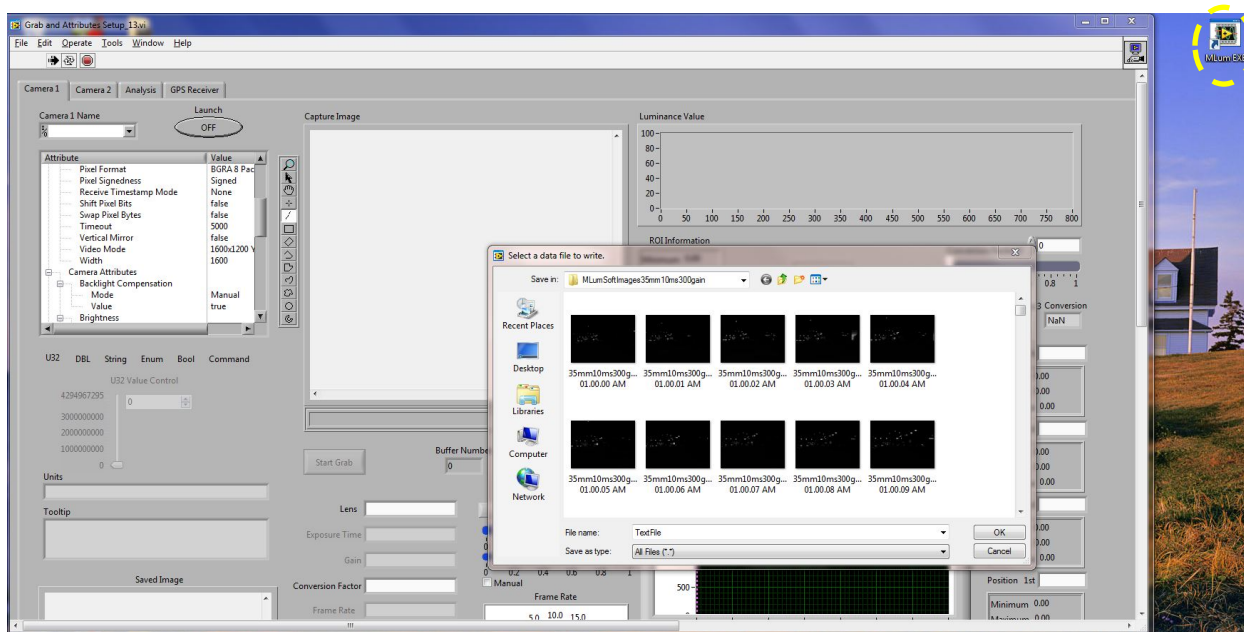


Figure 21. MLum Software at Startup.

STEP 2: Input the appropriate file location for storing the GPS log data, as shown in Figure 21, and then verify the GPS is turned on to 10 Hertz (Hz), as Figure 22 indicates.

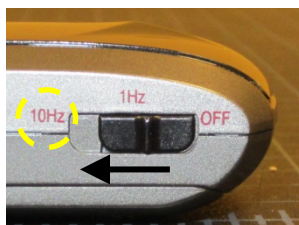


Figure 22. GPS Turned On to 10 Hz.

STEP 3: Access your camera by selecting it from the drop-down menu (yellow oval in Figure 23). Switch your camera on by selecting the OFF switch (orange oval in Figure 23). Select the Start Grab button (green oval in Figure 23) to start grabbing images from your camera.

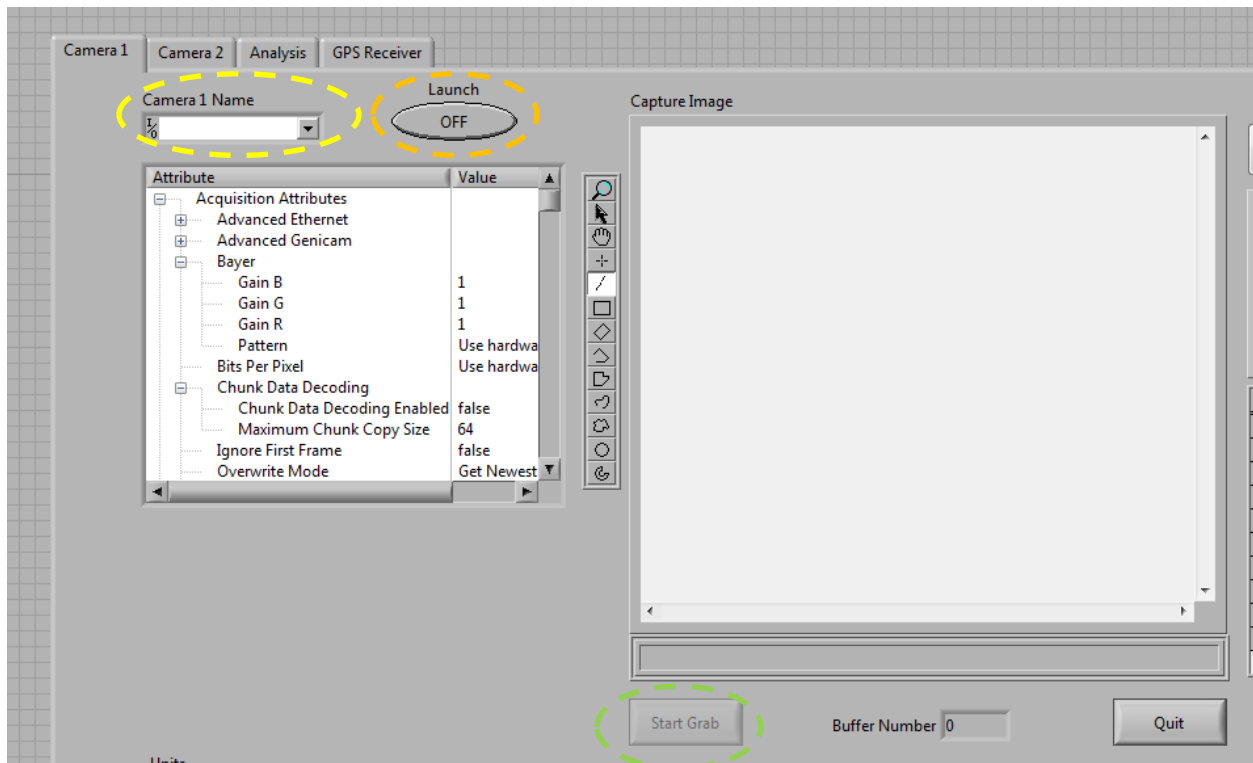


Figure 23. Access Camera.

STEP 4: Input the appropriate file location for storing the images (yellow oval in Figure 24). The authors recommend that users limit the number of images placed in one folder. This will help with file transfer and post-processing. Based on experience, the authors recommend that users minimize continuous data collection recording to a single folder to under 30 minutes at 1 image per second (ips), 15 minutes at 2 ips, and 5 minutes at 5 ips.

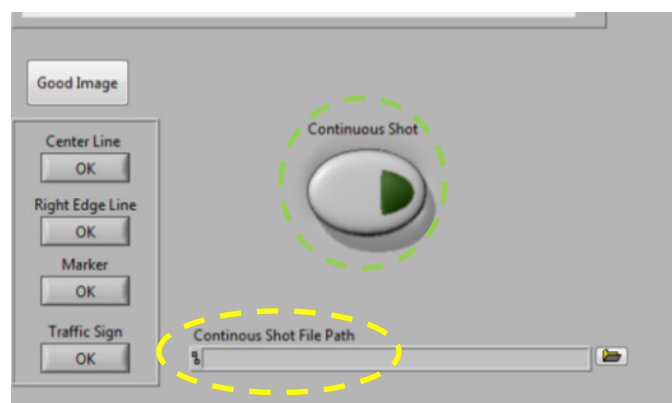


Figure 24. File Path for Storing Images.

STEP 5: Select the Continuous Shot button (green oval in Figure 24). The camera is now recording. If you have more than one camera, repeat steps 3 through 5 under the Camera 2 tab.

SAMPLE Mode

This is the recommended mode to collect data for nighttime evaluation of TCDs. In this mode, the data collection team consists of at least two persons, a driver and a software user. This mode works best with one camera at a time. You can set up multiple cameras for different regions, such as overhead guide signs versus shoulder-mounted signs, but you will have to switch between views when recording.

When using the SAMPLE Mode, follow these steps:

STEP 1: Select the executable MLum software to open it. See the icon marked with the yellow oval in Figure 25.

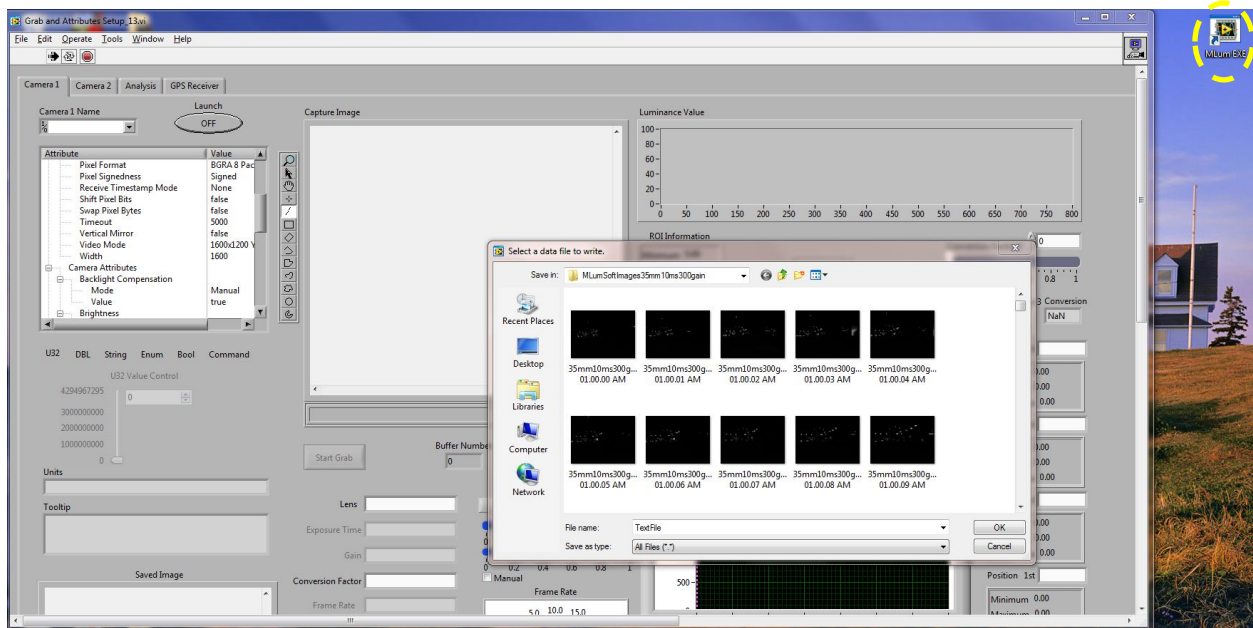


Figure 25. MLum Software at Startup.

STEP 2: Input the appropriate file location for storing the GPS log data, as shown in Figure 25, and then verify the GPS is turned on to 10 Hz, as Figure 22 indicates.

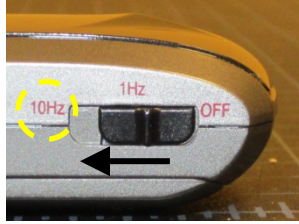


Figure 26. GPS Turned On to 10 Hz.

STEP 3: Access your camera by selecting it from the drop-down menu (yellow oval in Figure 27). Switch your camera on by selecting the OFF switch (orange oval in Figure 23). Select the Start Grab button (green oval in Figure 23) to start grabbing images from your camera.

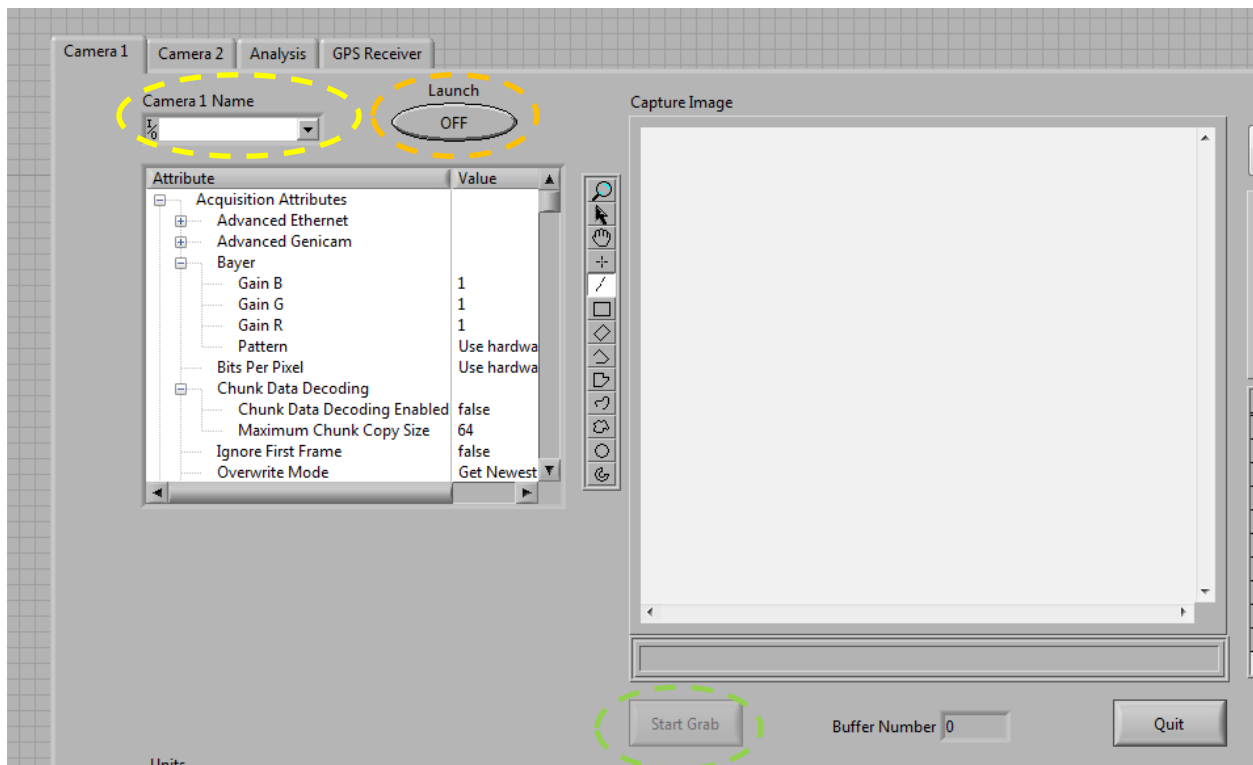


Figure 27. Access Camera.

STEP 4: Input the appropriate file location for storing the images (yellow oval in Figure 24). The authors recommend that the user limits the number of images placed in one folder. This will help with file transfer and post-processing. Based on experience, the authors recommend that users minimize continuous data collection recording to a single

folder to under 30 minutes at 1 image per second (ips), 15 minutes at 2 ips, and 5 minutes at 5 ips.

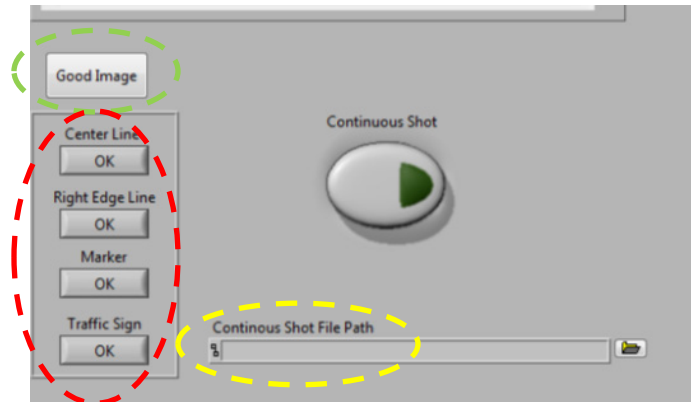


Figure 28. File Path for Storing Images.

STEP 5: You are now ready to collect data. When driving along the roadway, use the Good Image and Failure buttons to record single images. Select the Good Image button (green oval in Figure 28) to periodically record good images from a segment, and use the Failure buttons indicated in the red oval in Figure 24 to mark segments with failures.

Failures can be assessed in at least two ways:

- Subjective visual assessment by experienced personnel who have conducted nighttime TCD inspections before. This would be status quo with the added benefit of geocoding data at highway speeds with a visual luminance image record.
- Objective visual assessment using thresholding. The user must set thresholds for each of the conditions he/she intends to evaluate. For instance, if the right edge line will be evaluated, a sample edge line strip near established failure levels should be placed at 30 meters (100 feet) in front of the data collection vehicle, and then the threshold should be manually adjusted in the associated line graph. This should be repeated for each TCD evaluated.

If you have more than one camera, repeat steps 3 through 4 under the Camera 2 tab.

Calibration Mode

While TTI can complete these calibrations for TxDOT, the authors wanted to provide guidance on how to conduct the calibration of the system. The user must use each of the system cameras and lenses that he/she intends to use in the field, the mobile luminance data collection software, and a calibration grid and light source that provide a known luminance distribution. Figure 29a shows an example of one type of calibration grid that could be used. What is critical is to have a relatively uniform diffuse white reflective surface marked off with a grid system. The purpose of the grid system is to help ensure repeat measurements between the images taken with the system cameras and the known luminance values for each of the grid rectangles. Great expense could be expended on calibrated light sources and 99 percent diffuse material, but the authors recommend using either a calibrated spot photometer or full-image charge coupled device (CCD) photometer to assess the luminance of the calibration grid (see Figure 29b).

That data will be used to create a conversion factor for converting 12-bit mono-packed grayscale images into luminance images (see Figure 30). Table 2 details several conversion factors for the existing system under several different configurations.

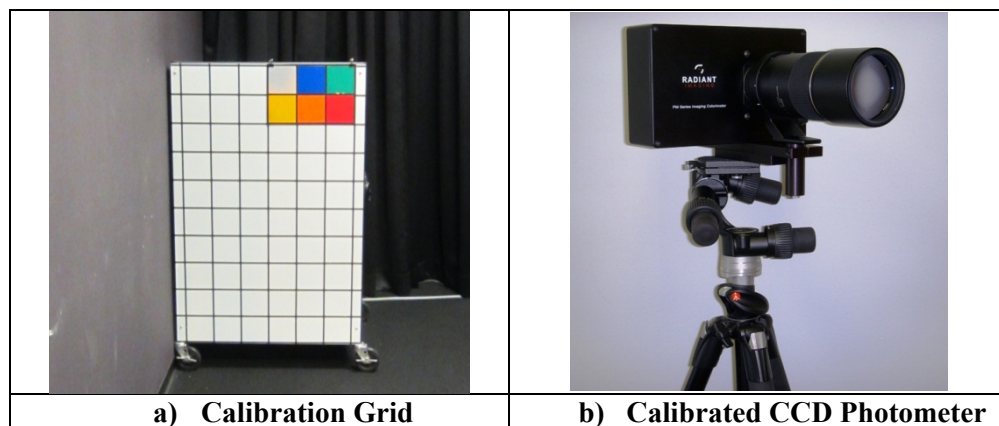


Figure 29. Calibration Equipment.

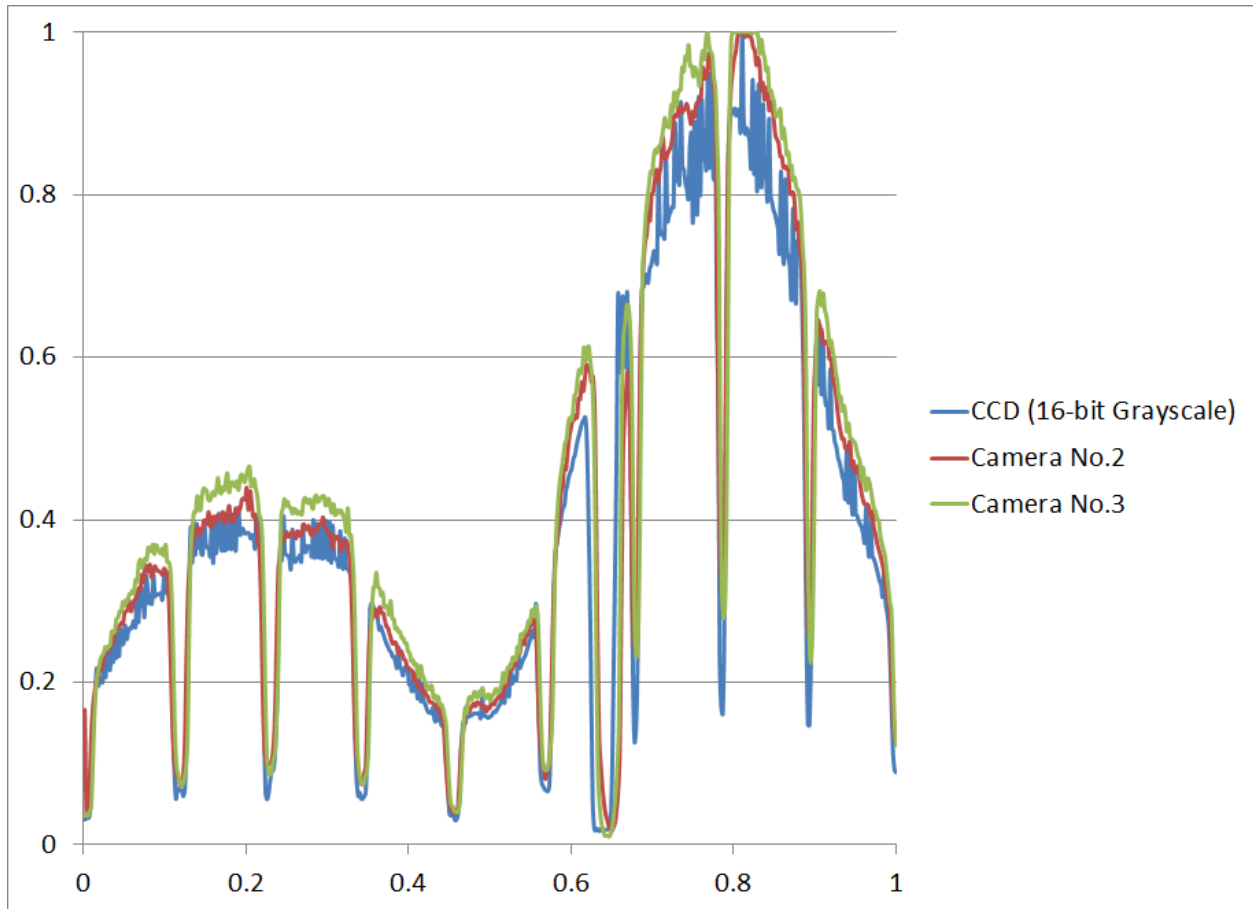


Figure 30. A 12-Bit Grayscale Image versus a 16-Bit Luminance Image.

Table 2. Grayscale-to-Luminance Conversion Factors.

Lens^a			Camera^b		Luminance^c		
Size (mm)	F-Stop	Focus	Exposure (ms)	Gain	Min	Max	Factor
12.5	2.8	∞	10	300			
35	2.8	∞	10	300			
50	2.8	∞	10	300			
75	2.8	∞	10	300			
		∞		300			
		∞		300			
		∞		300			

^aAll lenses were Fujinon, 1.5-megapixel, 1-inch diameter lenses. The V-Lambda filter was placed between the lens and the camera CCD imaging chip.

^bThe exposure time is based in milliseconds (ms) and uses an electronic shutter whereby the camera only reads the collective energy within a pixel over the preset duration. The gain is fixed below the midpoint of the available range, so it is low in comparison to the maximum available value. This particular value was chosen based on empirical laboratory testing whereby the system showed the most consistent performance regardless of lens type or setting or camera exposure.

^cThe minimum (min) and maximum (max) values describe the recommended dynamic range available for measurement. If the user believes that the luminance values that he/she would like to measure would exceed the range, the user should select more appropriate settings. The factor is the value that should be used to convert the grayscale image values into luminance. This is the value that should be input in the mobile luminance data collection software if it is not already preset.

Data Reduction Software

A brief discussion of how to use the data reduction software is presented below. The software currently offers the output data only in grayscale luminance form, so the user must further process the data. Follow the steps detailed below when using the software.

STEP 1: Start the data reduction software by double-clicking the executable file:

TTIDataReductionTool.exe. Figure 31 shows both the directory with the executable file selected and the GUI of the software.

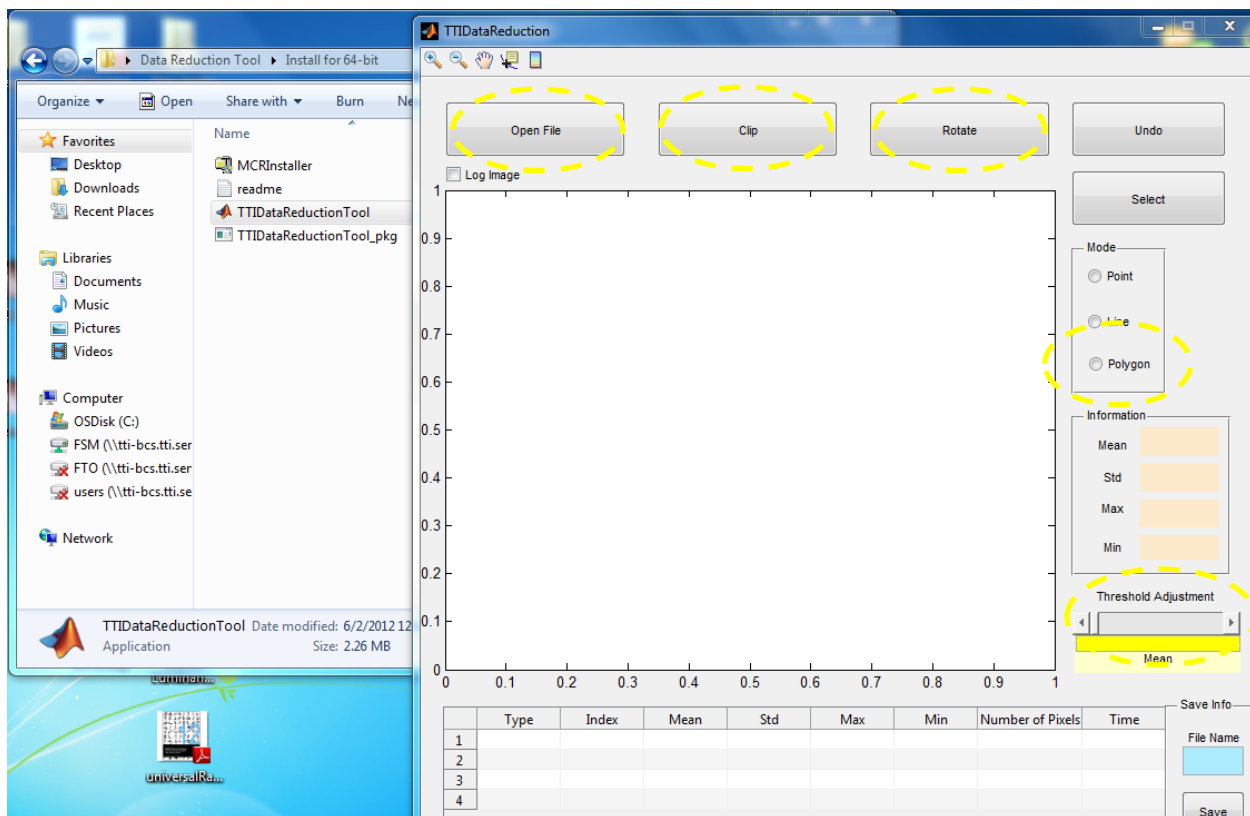


Figure 31. Startup of Data Analysis Software.

STEP 2: Load an image by clicking the Open File button indicated in Figure 31. Select an image that needs to be analyzed.

STEP 3: View the image. Several tools will help the user view each image, including a rotation tool and a clip tool (shown in Figure 31). Figure 32a shows the raw image, and Figure 32b shows an image that uses a 32-bit color pallet and an adjusted image color based on a log transform of the raw image grayscale values. This will allows to see dimmer objects, such as pavement markings.

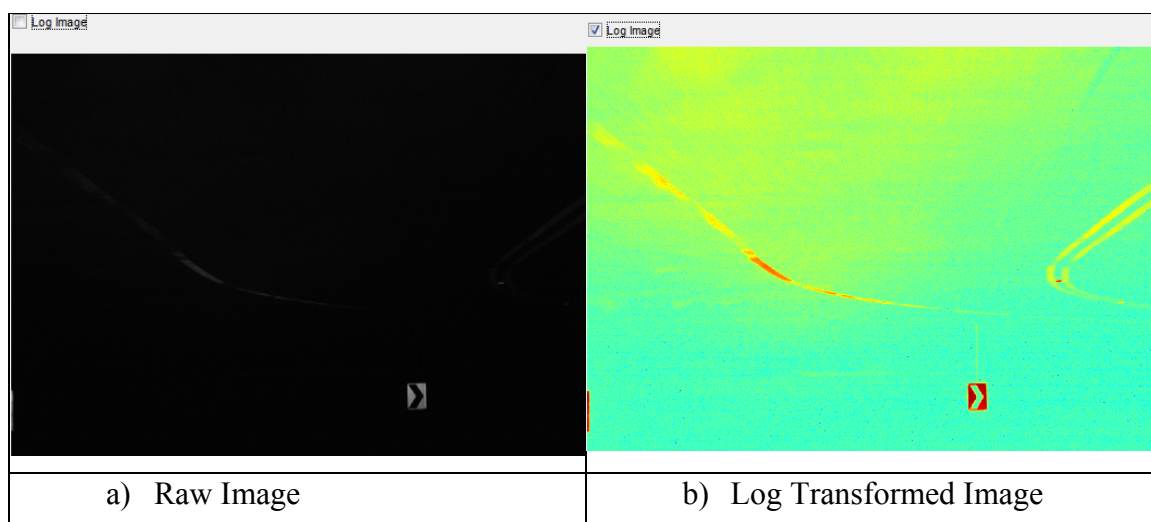


Figure 32. Image Options.

STEP 4: Measure the TCDs. Use the threshold slider bar to set the threshold. This will create a copy of the original image into a binary image that can be used to calculate general statistics associated with the original image. user can create the binary image by converting all values at or above the established threshold to 1. Then, all other points within the image will revert to 0. These two matrixes can be used to measure the mean and standard deviation of each TCD within a region. Now use the Polygon tool marked in Figure 31. Figure 33 and Figure 34 show examples of how the user can measure the different TCDs.

STEP 5: Convert the measurements. First, users must assess what the true bit depth of the images should be. The data analysis software automatically reports the image as if it were 16-bit grayscale. Since the current cameras report all output values except the sample size in 12-bit packed grayscale, the user must divide the values by 2^4 or 16. Finally, he/she will need to convert those values to luminance by multiplying by each conversion coefficient associated with each camera lens, f-stop, exposure, and gain, as documented in Table 2.

STEP 6: Apply these data to the guidelines presented in the final report.

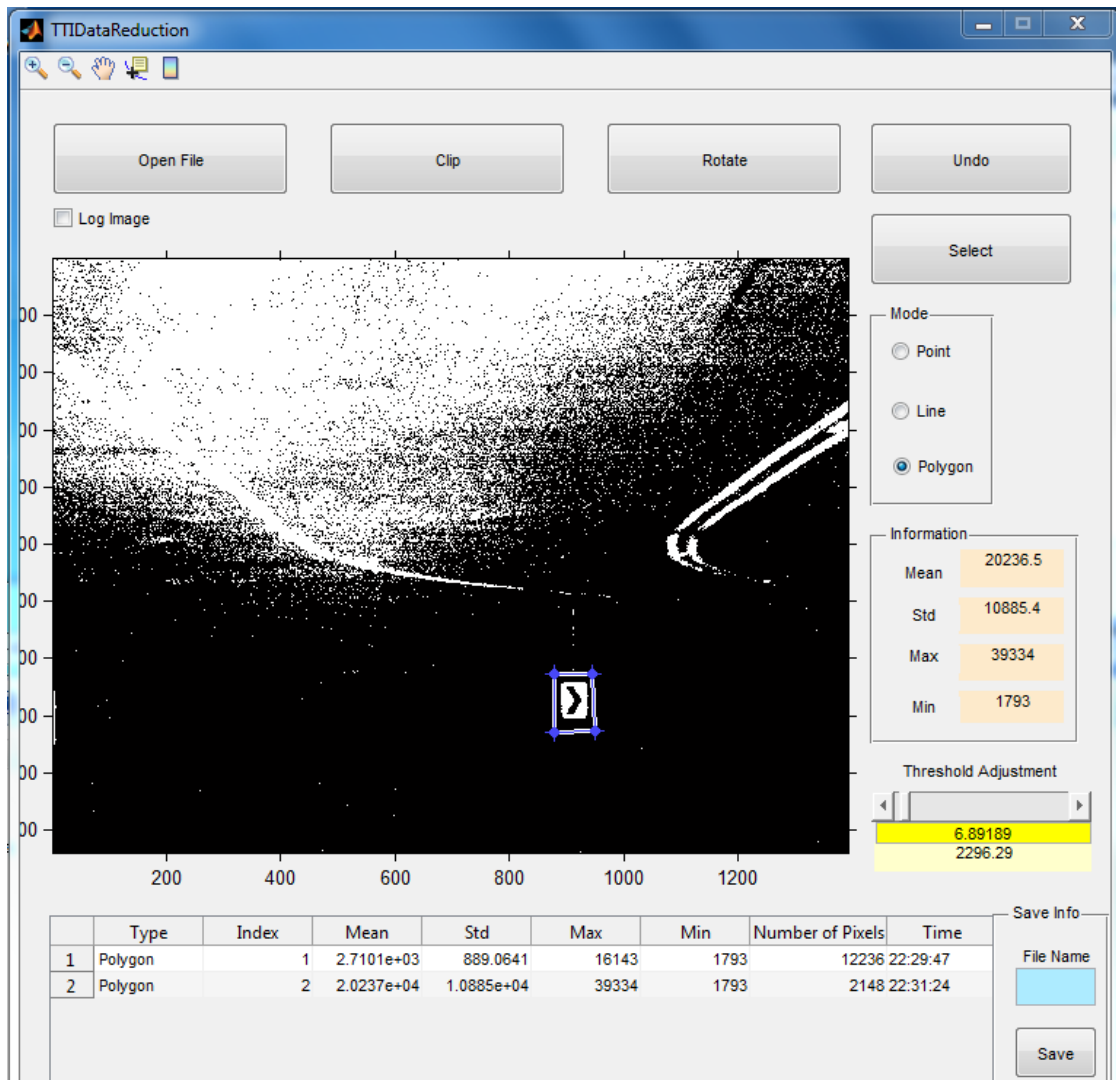


Figure 33. Image Analysis.

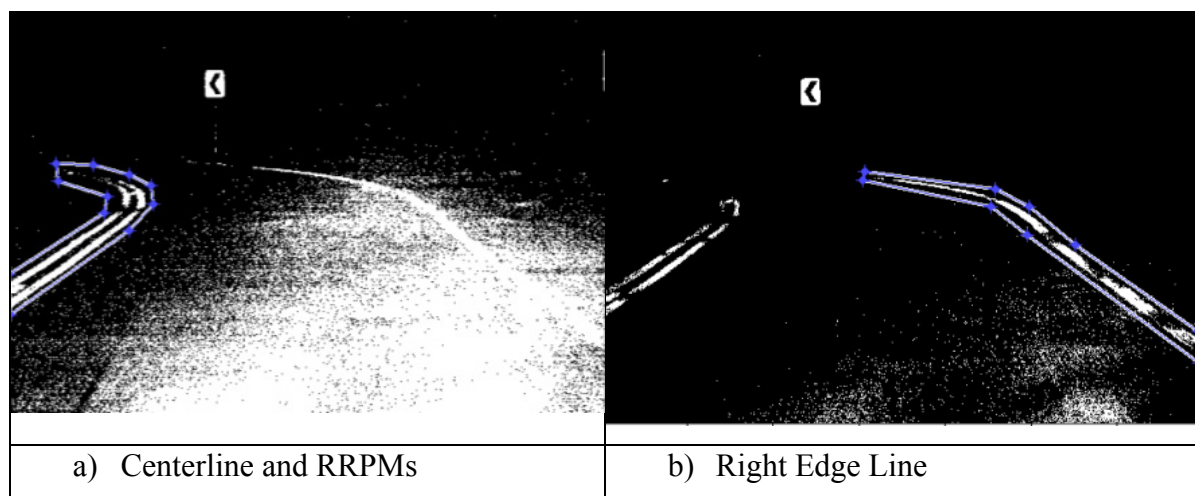


Figure 34. Pavement Markings and Markers.